BORON: ITS ABSORPTION AND DISTRIBUTION IN PLANTS AND ITS EFFECT ON GROWTH

By F. C. Cook,
Physiological Chemist, Bureau of Chemistry

INTRODUCTION

The experiments reported in this paper were made in connection with a cooperative study of borax and calcined colemanite as larvicides for the house fly conducted by the Bureaus of Entomology, Chemistry, and Plant Industry, of the Department of Agriculture. The object of this particular study was to determine the effect of boron-treated horse manure on plant growth and to study the absorption of boron and its distribution in the roots, stems, and fruit of plants grown on soil fertilized with this manure and on soil fertilized with untreated manure. The plants were grown in pots in the greenhouses of the Department and on open plots at Arlington Experimental Farm, Va.; Dallas, Tex.; Orlando, Fla.; and New Orleans, La. Analyses of the soil from several treated and untreated plots are included.[1]

Certain deposits of boron have been known for centuries, but the wide distribution of this element in mineral and vegetable matter has been recognized only during the last few years. Probably the first to record the presence of boron in plants were Wittstein and Apoiger (14),[2] who found it in the seeds of *Maessa picta*. Since then many observers have found boron in soils, rocks, fruits, and vegetables.

As soils in many places contain boron, it is not surprising that this element is widely distributed in small amounts in plants. It is also probable that boron is present in nearly all animal material. Bertrand and Agulhon (3) report its presence in the hair, horns, bones, liver, and muscles of animals. They detected boron in 27 species of animals, and state that it probably exists in all animals, being more common in those of marine origin. Boron was also found in human, asses', and cows' milk and in the eggs of the chicken, turkey, and goose.

The toxic effect of boron on plants was first shown in 1876 by Peligot (12), who noted a yellowing of the leaves of beans and reported that in many cases the yellow leaves fell from the plants. The previous year Heckel (8) reported that 1.25 per cent solutions of alkali borate retarded germination for from one to three days, and that 3 per cent of the alkali borate solutions stopped germination entirely. Loew (10, p. 374) states

[1] The writer desires to express his thanks to Mr. W. D. Hunter, of the Bureau of Entomology, for his material assistance in arranging for the experiments in the South.

[2] Reference is made by number to "Literature cited," pp. 889–890.

that certain algæ, such as Spirogyra and Vaucheria, are resistant to the action of boron. Morel (11), however, states that very weak solutions of boric acid arrest the development of lower fungi and similar organisms. He suggests that boric acid may be used, like copper, to attack such diseases as mildew and anthracnose. The effect of boron on the lower plants, fungi, yeasts, etc., has been but little studied.

Agulhon (1) and Bertrand (2) have stated that boron in small amounts acts as a stimulant to plant growth. Pellet (12) calls attention to some experiments which indicate that compounds of both manganese and boron, singly and combined, have no effect on the growth or yield of the sugar beet. He concludes that the results of other workers claiming a stimulation are too few and are untrustworthy.

Many investigations regarding the effect of boron on plants and plant growth have been reported, but no attempt to review all such experiments is made in this paper. For a review of this subject the publication of Haselhoff (7) and the recent work of Brenchley (4), where various inorganic plant poisons and stimulants are discussed, should be consulted.

EXPERIMENTAL WORK

Very few of the previous studies have included a quantitative estimation of the boron present in plants, and no experiments concerning the effects of calcined colemanite (crude calcium borate) on plant growth have been reported. As both borax and calcined colemanite are valuable larvicides for the house-fly maggot, it seems advisable to determine the effect of manure treated with both borax and calcined colemanite on the growth of a variety of plants.

The manure used in these tests was treated with the amounts of borax or calcined colemanite noted in the tables, and stood in the open for 10 days before it was applied to the soil. For the plot tests, the manure was applied at the rate of 20 tons per acre and was then plowed under, the ground harrowed, and sometimes rolled and reharrowed, before planting. In nearly all of these experiments borax or calcined colemanite was applied to the manure in larger quantities than were required to act as a larvicide—i. e., 0.62 per pound per 8 bushels, or 10 cubic feet. When the manure was mixed with the soil at the rate of 20 tons per acre, 216 pounds of borax per acre were present. Furthermore, the manure was not allowed to stand and leach for longer than 10 days; consequently, practically the entire amount of borax added reached the soil.

When 0.62 pound of borax was applied to each 8 bushels of manure and the weight of 8 bushels of manure estimated at 115 pounds (the average weight of fresh manure containing a large amount of straw), 100 pounds of manure contained 0.54 pound of borax, and when the manure was applied to the soil at the rate of 1 part to 40, the percentage of boron in the soil, calculating the weight of 1 acre of soil 6 inches deep as 1,750,000 pounds, was 0.0015.

Tests with tomato (*Lycopersicon esculentum*) and lettuce (*Lactuca sativa*) were made on plants which had been grown in boxes in greenhouses until they were 2 to 3 inches high, when they were transplanted in their respective pots containing the mixtures of manure and soil. The potatoes (*Solanum tuberosum*) tested were of the Green Mountain variety and the seeds used in growing the other plants were common varieties. The percentages of boric acid as recorded in the tables are calculated to a water- and ash-free basis. At least four pots for each treatment were employed in the pot tests. The plots at Arlington Farm were one-twentieth of an acre and those in the South about one-sixtieth of an acre in size. The tests with lettuce were carried out in benches, each 3 by 5 feet.

DESCRIPTION OF METHODS

Many tests for determining boron in foods and other material have been devised. When small amounts are present, as was the case in the present experiments, it is determined colorimetrically, using curcumin, the active principle in turmeric (*Curcuma longa* L.), a characteristic red color being given when boron is present.

In preparing the samples, the roots were separated from the plants. Both roots and plants were washed, dried, and cut into small pieces for analysis. In some cases the fruit also was tested. In such instances it was washed, dried, and ground for analysis. Boron was determined by the use of freshly prepared strips of curcumin paper, prepared by immersing large unfolded filter paper in a 0.2 per cent alcoholic solution of curcumin. The procedure was as follows: About 3 gm. of a dried sample were treated with sufficient saturated lime water to make the reaction alkaline. After a thorough mixing in platinum dishes, the samples were dried and heated in a muffle until all of the organic matter had burned off. Ten c. c. of water and a little hydrochloric acid were added and the solution was warmed, filtered, washed, and made to 100 c. c. volume. A 50 c. c. aliquot was usually taken for the determination of the boron, but this varied according to the amount present. To the 50 c. c. aliquot, or a smaller aliquot diluted to 50 c. c., placed in small porcelain evaporating dishes, 2 c. c. of hydrochloric acid were added, and strips of curcumin paper were suspended and allowed to dip into those solutions to the depth of one-fourth of an inch. In all cases standard boric-acid solutions, as well as blanks, were simultaneously employed. After four hours the colors on the strips of paper were compared and the percentage of boric acid determined.

In the case of soils, the boron soluble in weak hydrochloric acid, not the total boron, was determined. Fifty gm. of soil were shaken with 200 c. c. of a solution of hydrochloric acid (1:20) for one hour. This was filtered and 100 c. c. of the filtrate made alkaline with lime water, evaporated to dryness, and ashed. The ash was acidified with hydrochloric acid and the solution made to 100 c. c., a 50 c. c. aliquot being used for the colorimetric test. In some cases larger amounts of soil were used for the tests. From 2 to 3 gm. of the plant samples were used for moisture and ash determinations.[1]

RESULTS OF EXPERIMENTS

The results of the experiments are expressed in all the tables and text as percentages of boric acid. Some analyses of boron soluble in weak hydrochloric-acid extracts of soils are also reported. The form of the combination of the boron in plants is not known. The boron of soils is in part present in insoluble combinations with silica, and the absence of acid-soluble boron in some soils may be thus explained. Ash results are also reported for most of the plants analyzed. Separate analyses of the tops, roots, and fruits are tabulated.

In Table I analyses showing the distribution of ash and boron in the tops and roots of wheat (*Triticum* spp.) and beets (*Beta vulgaris*) 3 months old, grown in the presence of calcined colemanite and borax, with and without the addition of lime, are recorded. More boron was found in the tops than in the roots of both plants. The beets absorbed more boron than the wheat plants, especially from the soil treated with calcined colemanite. All of the control plants contained a little boron.

TABLE I.—*Percentage of boron in wheat and beets: Greenhouse pot tests*[a]

Series No.	Treatment of manure per 8 bushels.	Wheat (dry basis).				Beets (dry basis).			
		Tops.		Roots.		Tops.		Roots.	
		Ash.	Boron as boric acid, ash-free basis.	Ash.	Boron as boric acid, ash-free basis.	Ash.	Boron as boric acid, ash-free basis.	Ash.	Boron as boric acid, ash-free basis.
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1	0.75 pounds of calcined colemanite added	15.55	0.0103	20.00	Trace.	23.10	0.0315	17.74	0.0020
2	1.5 pounds of calcined colemanite added	12.96	.0097	24.76	Trace.	21.69	.0402	12.75	.0025
3	1 pound of borax added	12.58	.0097	33.48	0.0008	22.39	.0120	14.52	.0054
4	1 pound of borax and 1 ounce of lime added	8.51	.0122	23.39	.0029	23.07	.0172	....	.0097
5	1 pound of borax and 3 ounces of lime added	9.63	.0105	25.69	.0044	22.77	.0154	14.12	.0087
6	1 pound of borax and 9 ounces of lime added	11.07	.0173	26.24	Trace.	20.36	.0062	14.41	.0047
7	Control	9.20	.0013	23.76	Trace.	23.80	Trace.	14.56	.0013

[a] Forty parts of soil and 1 part of boron-treated manure were mixed in all the pot and bench tests.

A similar series of tests using tomatoes and cowpeas (*Vigna sinensis*) are recorded in Table II. The number and weight of the tomatoes obtained from four pots, which are also recorded, show the injurious

[1] The analyses were completed with the assistance of Mr. J. B. Wilson, of the Animal Physiological Chemical Laboratory, to whom the writer desires to express his indebtedness.

action of the boron alone and the benefit derived from adding lime. The tops of the tomatoes contained rather a large quantity of boron, the roots and fruit but traces. More boron was absorbed by the tomato plants when borax was added than with the addition of calcined colemanite. The addition of lime with the borax retarded the absorption of boron. The lowest percentage of dry matter was found in the tomatoes grown on the soil where borax alone was added. The tops of the control plants contained the least ash.

TABLE II.—*Boron in tomatoes and cowpeas: Greenhouse pot tests*

Series No.	Treatment of manure per 8 bushels.	Tomatoes.							
		Tops.		Roots.		Fruit.		Yield of fruit.	
		Ash.	Boron as boric acid (ash-free basis).	Ash.	Boron as boric acid (ash-free basis).	Dry matter.	Boron as boric acid (ash-free basis).	Number.	Weight.
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per cent.*		*Ounces.*
1	0.75 pound of calcined colemanite added.	13.13	0.0054	9.59	Trace.	6.04	Faint trace.	17	37.25
2	1.5 pounds of calcined colemanite added.	14.44	.0107	10.86	...do...	5.94	.....do.....	16	31.5
3	1 pound of borax added......	11.87	.0146	28.80	None..	4.72	.....do.....	10	10
4	1 pound of borax and 1 ounce of lime added.	12.95	.0123	13.76	...do...	....	....	15	33
5	1 pound of borax and 3 ounces of lime added.	12.15	.0072	10.66	...do...	5.26	Faint trace.	17	34
6	1 pound of borax and 9 ounces of lime added.	12.00	Trace.	19.43	...do...	5.85	.....do.....	18	35
7	Control.....................	10.12	...do...	21.88	Trace.	5.92	.....do.....	23	40.25

Series No.	Treatment of manure per 8 bushels.	Cowpeas (dry basis).					
		Tops.		Roots.		Fruit.	
		Ash.	Boron as boric acid (ash-free basis).	Ash.	Boron as boric acid (ash-free basis).	Ash.	Boron as boric acid (ash-free basis).
1	0.75 pound of calcined colemanite added..........................	*Per cent.* 9.27	*Per cent.* 0.0339	*Per cent.* 18.52	*Per cent.* 0.0033	*Per cent.* 3.68	*Per cent.* 0.0135
2	1.5 pounds of calcined colemanite added..........................	9.25	.0287	27.04	Trace.	3.90	.0106
3	1 pound of borax added...........	8.54	.0242	24.40	None.	3.36	.0133
4	1 pound of borax and 1 ounce of lime added..........................	10.96	.0115	10.01	....do.....	4.12	.0222
5	1 pound of borax and 3 ounces of lime added.....................	10.08	.0237	17.44	....do.....	3.01	.0097
6	1 pound of borax and 9 ounces of lime added.....................	11.36	.0302	20.64	....	3.40	.0029
7	Control...........................	7.84	.0068	22.58	None.	3.20	.0094

The tops of the cowpeas contained the most boron and the roots the least, the fruit being intermediate. The addition of lime with the borax did not influence the total amount of boron absorbed by the plants. The control cowpeas contained larger amounts of boron than the tomato control plants. The tops of the control cowpeas contained the least ash.

The results of the greenhouse, bench, and pot tests with lettuce and tomatoes are recorded in Table III. It is evident that the lettuce plants took up boron in proportion to the amounts present in the soil. The control lettuce contained the lowest percentage of solids and indicated the presence of boron. A slight chlorosis of the lettuce plants grown in series 1 and 2 was seen, but no injury to the roots was observed. The results of the analyses of the upper and lower 6 inches of soil in the benches show an even distribution of the boron.

TABLE III.—*Boron in lettuce and tomatoes: Greenhouse bench and pot tests*

Series No.	Treatment of manure per 8 bushels.	Lettuce (entire plant).		Soluble boron as boric acid in soil on which lettuce was grown.	
		Dry matter.	Boron as boric acid (dry basis).	Upper 6 inches of soil.	Lower 6 inches of soil.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	0.75 pound of borax added	11.6	0.00036	0.0012	0.0010
2	1.25 pounds of borax added	10.0	.00064	.0022	.0028
3	Control	9.0	.00020	Faint trace.	Faint trace.
4	0.5 pound of borax added		.00036		
5	0.62 pound of borax added		.00042		
6	0.75 pound of borax added				
7	Control		.00015		

Series No.	Treatment of manure per 8 bushels.	Tomatoes.					
		Tops (dry basis).		Fruit (fresh basis).		Yield.	
		Ash.	Boron as boric acid (ash-free basis).	Dry matter.	Boron as boric acid (water and ash free basis).	Number.	Weight.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Ounces.*
1	0.75 pound of borax added	12.98	0.0089	6.55	Faint trace.	123	157
2	1.25 pounds of borax added	12.94	.0196	6.60	do	101	139¾
3	Control	10.10	.0009	6.75	do	120	159½
4	0.5 pound of borax added	10.01	.015	8.10	0.0002		
5	0.62 pound of borax added	10.77	.016	8.01	.0004		
6	0.75 pound of borax added	7.72		7.51	.0003		
7	Control	7.72	.0015	8.00			

Tomato plants 1, 2, and 3, Table III, were 6 months old at the time of analysis. The yield of fruit from three pots in each series, 1, 2, and 3, showed no reduction in the case of the 0.75-pound borax application, but the 1.25-pound borax application reduced the yield. The dry matter of the control fruit, series 3, is higher than in series 1 or 2, and the ash of the control tops, series 3, is lower than the ash for the tops, series 1 and 2. The tomato plants, series 4, 5, 6, and 7, were younger and smaller than those of series 1, 2, and 3. In all the tomato plants (Table III) the tops contained practically all the boron, the fruit showing only traces.

The results with wheat grown in plots at Arlington Farm, Va., are given in Table IV. The manure was applied at the rate of 20 tons per acre. The wheat was planted in October, 1913, and harvested in June, 1914, the soil samples being tested at the time of harvesting. On the borax plot the wheat plants which were yellow during the winter, became green and normal in appearance in the spring. The yield of wheat from the borax plot was 90 per cent of the control, but larger than that from an unmanured plot which was simultaneously tested. The amount of borax added to the borax plot was about four times that necessary to act as a larvicide, but only a trace of boron was found in the wheat grain or straw. The wheat grains were sound and the nitrogen and ether-extract results of the control differed very little from those of the wheat and straw from the borax-treated plot. A trace of boron was found in the grains and straw from the borax plot, and the borax-treated soil showed 0.003 per cent of boric acid. The soil sample from the borax plot contained more nitrates than the control sample. Nitrogen was estimated by the Kjeldahl-Gunning method, and nitrates by the method recommended by the American Public Health Association.

TABLE IV.—*Percentage of boron in wheat, straw, and soil: Plot tests at Arlington Farm, Va.*

Series No.	Treatment of manure per 8 bushels.	Material.	Nitrogen.	Nitrogen as ammonia (MgO method).	Nitrogen as nitrates.	Ether extract.	Acid-soluble boron as boric acid.
1	2 to 3 pounds of borax added.	Wheat grains	2.15			1.70	Faint trace.
		Wheat straw	.281			2.12	Do.
		Soil 3 to 4 inches deep	.09	0.004	0.0018		0.003.
2	Control	Wheat grains	2.21			1.77	None.
		Wheat straw	.323			2.27	Do.
		Soil 3 to 4 inches deep	.09	.003	.0012		Do.

Results of the analyses of soybeans (*Glycine hispida*), string beans (*Phaseolus vulgaris*), and potato plants grown on plots at Arlington Farm, Va., are recorded in Table V. The roots and beans of the soybeans contained about equal amounts of boron, and rather large quantities were found in the tops of all the plants analyzed. There was a more equal distribution of boron in the roots, tops, and beans of the string beans than in the case of the soybeans.

The potatoes showed only traces of boron in the tops, the largest part of the boron being found in the roots, although the tubers contained a fairly large amount. All control plants contained a little boron. The addition of lime with the borax did not prevent the absorption of boron by the plants, as much boron being absorbed from the calcined-colemanite plots as from the borax plots.

TABLE V.—*Percentage of boron in soybeans, string beans, and potatoes: Plot tests at Arlington Farm, Va.*

Series No.	Treatment of soil per square rod.	Boron as boric acid (dry basis).								
		Soybeans.			String beans.			Potatoes.		
		Roots.	Tops.	Beans.	Roots.	Tops.	Beans.	Roots.	Tops.	Potatoes.
1	1.61 pounds of calcined colemanite added....	0.0086	0.0048	0.0092	0.0044	0.0075	0.0045	0.0170	0.0012	0.0094
2	2.88 pounds of calcined colemanite added....	.0160	.0076	.0136	.0083	.0177	.0213	.0144	Trace.	.0021
3	3.96 pounds of borax added...............	.0124	.0047	.0104	.0086	.0093	.0117	.0354	..do...	.0066
4	3.96 pounds of borax and 2 pounds of lime added...............	.0126	.0040	.0164	.0093	.0099	.0080	.0165	..do...	.0019
5	2 pounds of lime added.	.0030	.0008	.0036	.0050	None.	.0042	Trace.	None.	.0010

In Table VI results of the analyses of corn (*Zea mays*), wheat, peas (*Pisum sativum*), and oats (*Avena sativa*), grown on plots at New Orleans, La., and Dallas, Tex., are recorded. The entire plants, which were 3 months old and small, were used. The corn and wheat plants took up equal amounts of boron. Soluble boron was found in all nine samples of soil from New Orleans, while only two of the five samples from Dallas contained any. The peas absorbed more boron than the oats, especially in series 1, 2, and 3.

TABLE VI.—*Percentage of boron in corn, wheat, peas, oats, and soil: Plot tests at New Orleans, La., and Dallas, Tex.*

Series No.	Treatment of manure per 8 bushels.	New Orleans, La.			Dallas, Tex.		
		Boron as boric acid (entire plant, dry basis).		Soluble boron as boric acid in soil, sample taken 4 inches deep.	Boron as boric acid (entire plant, dry basis).		Soluble boron as boric acid in soil, sample taken 3 inches deep.
		Corn.	Wheat.		Peas.	Oats.	
1	0.5 pound of borax added..........................	0.013	0.011	0.0006	0.010	0.001	0
2	0.62 pound of borax added.........................	.015	.015	.0009	.010	.006	Trace.
3	Control..	Trace.	Trace.	Trace.	.003	0	0
4	0.75 pound of borax added.........................	....	....	.0003	.040	.025	0
5	1.25 pounds of borax added........................	....	....	.0013	.026	.025	Trace.
6	Control..	....	....	Trace.	.0005	0	0
7	0.75 pound of calcined colemanite added...........	....	....	.0008	....	....	....
8	1.50 pounds of calcined colemanite added..........	....	....	.0032	....	....	....
9	Control..	....	....	Trace.	....	....	....

TABLE VII.—*Percentage of boron and ash in radishes, string beans, cowpeas, peas, and soil: Plot tests at Orlando, Fla.*

Series No.	Treatment of manure per 8 bushels.	Radishes (dry basis).				String beans (dry basis).			
		Tops.		Roots.		Tops.		Roots.	
		Ash.	Boron as boric acid (ash-free basis).	Ash.	Boron as boric acid (ash-free basis).	Ash.	Boron as boric acid (ash-free basis).	Ash.	Boron as boric acid (ash-free basis).
1	0.75 pound of borax added	34.44	0.162	50.08	0.039	....	0.086	22.98	0.011
2	1.25 pounds of borax added	49.49	.226	51.12	.087	17.56	.080	14.89	.015
3	Control	45.25	.018	45.04	.010	22.80	.011	....	.007

Series No.	Treatment of manure per 8 bushels.	Cowpeas (dry basis).				Peas (entire plant, dry basis).	Soluble boron as boric acid found in sample of soil 3 to 4 inches deep.
		Tops.		Roots.			
		Ash.	Boron as boric acid (ash-free basis).	Ash.	Boron as boric acid (ash-free basis).	Boron as boric acid.	
1	0.75 pound of borax added	29.49	0.162	35.15	0.222	0.212	0.0006
2	1.25 pounds of borax added	33.22	.140	45.68	.240	.229	.0010
3	Control	20.18	.024	....	.029	.024	.0003

In Table VII the boron content of radish (*Raphanus sativus*), string-bean, cowpea, and pea plants, grown on borax and control plots at Orlando, Fla., is given. An appreciable amount of soluble boron was found in the soil samples from all three plots. The radish plants contained a large amount of boron in the tops, as well as an appreciable quantity in the roots. The string beans did not absorb as much boron as the radishes, but contained a large percentage of the absorbed boron in the tops. The cowpeas absorbed large amounts of boron, more being found in the roots than in the tops. The pea plants also absorbed boron in great quantities. All the control plants contained boron to a marked degree, which is not surprising, as 0.0003 per cent of soluble boron was found in the control soil sample examined at the close of the test.

As there was little rain at Orlando while these tests were being conducted, and as relatively large quantities of soluble boron were found in the samples of soil tested, it is not surprising that the plants absorbed large amounts of boron.

DISCUSSION OF EXPERIMENTAL WORK

It apparently made little difference in the quantities of boron absorbed by the various plants whether it was added to the manure used on the soil in the form of calcined colemanite or as borax. The addition of lime to the borax also showed no definite action in preventing the absorption of boron, although with beets (Table I) and with one series of tomatoes (Table II) such a reduction is indicated where the largest application of lime was made. Most of the plants analyzed took up boron in proportion to the amounts present in soluble form in the soil.

The leguminous plants, which were most easily injured by boron, absorbed larger amounts than the other plants tested, while wheat and oats absorbed but little boron. It is particularly noteworthy that the wheat grown at Arlington Farm, Va., on soil fertilized with manure heavily treated with boron showed only traces of boron in the grain and straw. Haselhoff (7) found boron in the stalk of maize, but not in the grain.

The most striking differences in the absorption and distribution of boron are shown by the leguminous plants, where a more even distribution between roots, tops, and fruit is found. Potatoes also showed rather a large quantity of boron in the roots and tubers, but only a small amount in the tops. Succulent plants like beets also absorbed boron. On the other hand, tomatoes and wheat showed only traces of boron in the fruit and but little in the roots. Agulhon (1) has investigated the action of boric acid on wheat, using synthetic sterile liquid media, including both soil and water cultures. He recommends 0.0012 per cent of boron to obtain the best growth. In these tests, when borax was added at the rate of 0.62 pound to each 8 bushels of manure and this manure applied to the soil at the rate of 15 tons per acre, 0.0015 per cent of boron was added to the soil.

The fact that all control plants contained a little boron shows the wide distribution of boron in the soil. From the large amounts taken up by the control plants grown at Orlando, Fla., it appears that the soil there contains more than the soil at Dallas, Tex., New Orleans, La., or Arlington Farm, Va.

The ash results of the various portions of the plants analyzed vary considerably, and the variations are not in a definite direction.

A spotting or yellowing of the leaves of plants, which was first noted by Hotter (9) and later reported by several investigators, was observed in these experiments when boron was present in the soil to any extent. In the case of the tomato plants, Table II, a yellowing of the leaves was noted when borax was used at the 0.75-pound rate, but the yield was unaffected. In some of the legumes—namely, string beans, soybeans, and peas—a noticeable yellowing of the leaves was observed when borax was added at the rate of 0.75 pound, and in these cases a reduction in stand took place. The wheat plants grown at Arlington Farm on the plot fertilized with manure treated with from 2 to 3 pounds of borax to each 8 bushels, as noted on page 883, were yellow during the first 3 or 4 months of growth. When the growth started in the spring, however, the plants became green, and the yield of the grain was 90 per cent of the control yield, more than that obtained from the unmanured control plot. The yellowing of the leaves is an unmistakable sign of injury, although in some cases the plant can recover, or at least is not sufficiently injured to cause a reduction in the yield.

Haselhoff (7) states that the action of boron is more marked on beans than on oats or corn, and that it can be seen when small amounts of boron are present in the soil and when no action injurious to plant growth is evident. He says further that small amounts of boron stimulate the growth of beans and corn, while large amounts produce injury. In his experiments beans absorbed boron in proportion to the amount present in the soil up to a certain limit. The plants examined by Haselhoff contained from 0.04 to 0.17 per cent of boron, which is more than was found in these experiments, with the exception of the plants grown at Orlando, Fla. (Table VII). He suggests that for safety the amount of boron in the soil be less than 0.0001 per cent. According to Brenchley (5), peas are stimulated by relatively high concentrations of boric acid, but with larger applications of boric acid the toxic action was well marked on the leaves, which tend to become brown and to die in a characteristic manner.

There is some evidence in the literature to indicate that small amounts of boron stimulate plant growth. Brenchley (5) states that below a certain dilution boron tends to produce stronger roots and shoots. Large amounts of boron are known to be toxic to practically all plants, with the exception of certain fungi.

In these experiments, where in most cases more boron was added than was necessary to act as a larvicide, no stimulating action was noted. On the contrary, an injurious action was seen with leguminous plants, which became yellow and did not show a good stand. Tomatoes, beets, lettuce, potatoes, radishes, corn, oats, and wheat appeared normal when grown in the presence of amounts of boron which produced injury to leguminous plants. When borax is added to manure at the rate of 0.62 pound to each 8 bushels and the manure is applied to the soil at the rate of 15 tons per acre, 0.0011 per cent of boron is added to the soil. This quantity of boron may injure leguminous plants, but did not injure the other plants tested, although no stimulation was noted. If the borax-treated manure is mixed with untreated manure, as would be done in many cases, since it is necessary to treat manure with borax to destroy fly larvæ during only a portion of the year, it is possible that the percentage of boron would be sufficiently reduced to bring about a stimulating action on plant growth.

In connection with the stimulating action of boron, it may be mentioned that nitrites and nitrates were detected in three or four borax-treated manure piles at New Orleans (6, p. 19), while the corresponding control piles contained no nitrites or nitrates, and several soils fertilized with borax manure have shown more nitrates than the check soils. A stimulating action of boron on the nitrifying bacteria seems to follow in certain cases.

The results at Orlando, where the same amounts of boron were added to the soil as at other points, but where the toxic action of the boron was marked and where soluble boron was found in the soils after several months, indicates that many factors are involved in the absorption of boron and its effect on plants, and that definite conclusions in studies of this nature should be drawn with great care. These results are submitted as a preliminary study of this question. It is our purpose to test the cumulative action of boron in soils.

SUMMARY

(1) It apparently made little difference in the quantity of boron absorbed by the plants tested whether boron was added to the soil as borax or as calcined colemanite. The addition of lime with borax had no definite effect in preventing the absorption of boron. Wheat and oats absorbed very little boron, while leguminous and succulent plants absorbed comparatively large amounts.

(2) Wheat, beets, cowpeas, and tomatoes grown in pots in the greenhouses contained boron principally in the tops of the plants, and, with the exception of the beets, comparatively little or none in the roots.

(3) The fruit of the tomato plants contained only traces of boron, while the fruit of the cowpea contained large quantities. Lettuce grown in the greenhouse absorbed boron in proportion to the amounts present in the soil.

(4) Potatoes grown in the open showed, when mature, a small amount of boron in the tops and relatively large amounts in the roots and tubers.

(5) The leguminous plants, string beans, soybeans, and cowpeas, which were very sensitive to boron, showed when grown in plot tests a more equal distribution of the boron among the roots, tops, and fruit than the other plants tested.

(6) Radishes grown in plots contained much larger quantities of boron in the tops than in the roots. Analyses of entire plants of wheat, corn, peas, and oats grown on plots in the South showed the absorption of boron in all cases, the peas absorbing the most. All of the control plants contained at least a trace of boron.

(7) Samples of soil from some of the control plots showed the presence of acid-soluble boron, while several similar samples of soil from certain boron-treated plots showed no acid-soluble boron. Usually more soluble boron was found in the treated soil than in the control soil.

(8) The yield of wheat from a plot heavily treated with borax was 90 per cent of the manured-control yield and greater than the yield from the unmanured control. The wheat grains were sound and contained but a trace of boron.

(9) The yield of tomatoes in pot tests was unaffected when borax was added in amounts to produce 0.0018 per cent of boron in the soil, but when the amount was increased to 0.0030 per cent, a reduced yield resulted.

(10) Numerous factors influence the absorption, distribution, and action of boron in plants.

(11) No more than 0.62 pound of borax or 0.75 pound of calcined colemanite should be added to each 10 cubic feet of manure, and when using the boron-treated manure in growing leguminous plants, the manure should be mixed with untreated manure before being applied to the soil. For other plants, boron-treated manure should not be used at a higher rate than 15 tons per acre.

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